The Reflection of X-rays by Crystals. (II.)

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This note is a supplement to a paper on the reflection of X-rays by crystals which has been recently communicated to the Royal Society.* It is there shown that the wave-length of a homogeneous beam of X-rays can be found accurately in terms of the spacing of the elements of a crystal. There has been some doubt as to the actual arrangement of the atoms in the crystal and in consequence it was not possible in the paper quoted to draw any final conclusions as to wave-length values. From the work now described by W. L. Bragg it appears that the reflection phenomena lead to a more definite knowledge of crystal structure, and we may now complete various quantitative determinations.

The elementary volume in rock-salt is a cube with 1 atom of sodium at each of four corners and 1 atom of chlorine at each of the other four. In other words the number of elementary volumes in any space of measurable dimensions is equal to the number of atoms in that space.

The number of molecules in 1 c.c. of NaCl is

$$2{\cdot}15/58{\cdot}5 \times 1{\cdot}64 \times 10^{-24} = 2{\cdot}24 \times 10^{22}$$

(The weight of the H atom is taken to be $1{\cdot}64 \times 10^{-24}$)

The number of atoms is twice as great and the elementary cube volume is therefore $1/4{\cdot}48 \times 10^{22} = 2{\cdot}23 \times 10^{-23}$. The edge of the cube is $2{\cdot}81 \times 10^{-8}$; this is the distance between consecutive reflecting planes parallel to (100).

The principal bundle of homogeneous X-rays from a platinum anticathode is stated in the paper quoted to be reflected at the (100) face of rock-salt at a glancing angle of 11·55°. Recent observations with better apparatus show that this bundle is really double, consisting of two separate sets whose wave-lengths differ from each other by a little less than 2 per cent. of either; they also show that the first estimate was a little too high. For the purpose of the present argument it is sufficiently accurate to ignore the division and assume the angle to be 11·3°. This gives a wave-length

$$(2\,d \sin\theta) = 2 \times 2{\cdot}81 \times 10^{-8} \times 0{\cdot}196 = 1{\cdot}10 \times 10^{-8}$$

The wave-lengths of other homogeneous rays can then be found easily as soon as their angles of reflection are known.

* W. H. Bragg and W. L. Bragg, these 'Proceedings,' A, vol. 88, p. 428.

A bulb having a nickel anticathode gives one weak beam of homogeneous rays reflected at a glancing angle of $17{\cdot}2°$; the corresponding wave-length is $1{\cdot}66 \times 10^{-8}$. A tungsten anticathode gives a weak beam at an angle of $12{\cdot}9°$ and the wave-length is therefore $1{\cdot}25 \times 10^{-8}$. An iridium anticathode gives a more complicated spectrum which is not yet completely analysed.

On the basis of existing theories certain numerical relations might be expected to subsist between these quantities, and it is interesting to see how closely they are fulfilled.

In the first place the "quantum" energy for a wave-length $1{\cdot}10 \times 10^{-8}$ is $6{\cdot}55 \times 10^{-27} \times 3 \times 10^{10}/1{\cdot}10 \times 10^{-8} = 1{\cdot}78 \times 10^{-8}$ ergs. This should be the value of the energy of the cathode ray which can excite this particular X-ray, as well as of the cathode ray which it can excite. The quality of the X-ray can be expressed in terms of its mass-absorption coefficient in aluminium. The estimate of this quantity given in the first paper quoted was too low; the influence of the scattered radiation was not effectively removed. By taking the mean of the radiation on either side of the B peak and subtracting this from the radiation at the peak itself with and without an Al screen a value 23·7 is found. That the radiation is very homogeneous is ascertained in the usual way.

Now according to Barkla's experimental results, X-rays of this quality are such as are given in the K series by a radiator of atomic weight 74 and in the L series by a radiator of atomic weight 198. The atomic weight of platinum is 195, and this can hardly be a coincidence. It may be calculated from Whiddington's results* that the energy of the cathode ray required to excite the X-ray of the K series in an atom of weight 74 is about $2{\cdot}14 \times 10^{-8}$ ergs, which is in very satisfactory agreement with the "quantum" energy calculated above.

From the foregoing it seems reasonable to take the radiation of the B peak as equivalent to the characteristic radiations of an atom of atomic weight 74 (or perhaps 72·5, the equivalent of platinum in the K series), while the experiment with the nickel anticathode may be taken to show that the wave-length $1{\cdot}66 \times 10^{-8}$ belongs to nickel (at. wt. 59) and in the same way that of $1{\cdot}25 \times 10^{-8}$ to tungsten in the L series or its equivalent (at. wt. 67) in the K series. Now the quantum energies should be proportional to the frequencies and at the same time according to Whiddington to the squares of the atomic weight. The squares of 59, 67, and 74 (or 72·5) are in the ratio 100 : 130 : 157 or 150, while experiment shows that the frequencies are in the ratio $1/1{\cdot}66 : 1/1{\cdot}25 : 1/1{\cdot}10$, or 100 : 132 : 151. The frequency is therefore very nearly proportional to the quantum energy.

* 'Proc. Camb. Phil. Soc.,' vol. 16, p. 150.

Lastly, though the absorption coefficient of the tungsten peak has not yet been satisfactorily measured, it may be doubtless supposed to be a little less than that of the A peak of platinum, since its wave-length is slightly less. A recent measurement of the latter quantity gives the value 35·5 and the absorption coefficient of the characteristic radiation of tungsten is given by Barkla as 33.

The Structure of Some Crystals as Indicated by their Diffraction of X-rays.

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[Plate 10.]

A new method of investigating the structure of a crystal has been afforded by the work of Laue* and his collaborators on the diffraction of X-rays by crystals. The phenomena which they were the first to investigate, and which have since been observed by many others, lend themselves readily to the explanation proposed by Laue, who supposed that electromagnetic waves of very short wave-lengths were diffracted by a set of small obstacles arranged on a regular point system in space. In analysing the interference pattern obtained with a zincblende crystal, Laue, in his original memoir, came to the conclusion that the primary radiation possessed a spectrum consisting of narrow bands, in fact, that it was composed of a series of six or seven approximately homogeneous wave trains.

In a recent paper† I tried to show that the need for assuming this complexity was avoided by the adoption of a point system for the cubic crystal of zincblende which differed from the system considered by Laue. I supposed the diffracting centres to be arranged in a simple cubic space lattice, the element of the pattern being a cube with a point at each corner, and one at the centre of each cube face. A simpler conception of the radiation then became possible. It might be looked on as continuous over a wide range of wave-lengths, or as a series of independent pulses, and there was no longer any need to assume the existence of lines or narrow bands in its spectrum.

* W. Friedrich, P. Knipping, and M. Laue, 'Münch. Ber.,' June, 1912.

† 'Camb. Phil. Soc. Proc.,' November, 1912.